

Note to the reader

This report was originally prepared by J.E. Hanna Associates Inc. in June 1987. In July, 1988, J.E. Hanna Associates Inc. amalgamated with Victor & Burrell, Research and Consulting and Heeney Associates to form VHB, Research and Consulting Inc. This final report is issued under the corporate responsibility of VHB.

The draft report has been reviewed, and minor editorial corrections have been made to this final version. However, neither the substance of the report nor the data it contains has been updated. Since the report was prepared, several actions have occurred which may indicate changes to the willingness of Canadian and Ontario society to incur costs to avoid environmental loadings. These changes include:

- the federal government has accelerated the implementation timetable for reducing lead in gasoline
- the Ontario government has imposed differential taxes on leaded and unleaded gasoline to bring the retail cost of leaded gasoline up to that for unleaded.

We have not investigated the extent to which these represent changes in society's willingness to pay. There may be other factors which account for these changes. For example, it may be that these changes are the result of changes in the estimated toxicity of environmental lead.

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Executive summary

Purpose

To provide a basis for assessing society's willingness-to-pay to reduce loadings of toxic contaminants to the environment.

Scope and method

Willingness-to-pay is considered by reviewing unit cost from three cases in which society has accepted or rejected actions which will result in reduced loadings of toxic contaminants to the environment:

- A proposed remedial action program to reduce the level of mercury in the Wabigoon River and Clay Lake,
- The cleanup of PCBs spilled during transport in Kenora,
- A regulation to reduce the allowable levels of lead in gasoline.

For each case, the quantity of chemicals affected by the measure is estimated, costs of the measure are estimated, and a unit cost is calculated. The relevance of each case to the OWMC situation is discussed.

The source of information for the mercury cleanup and the lead regulations is published reports. Information on the Kenora spill was obtained from the Ontario Ministry of the Environment.

Premises and postulates

OWMC provided the following premises which guided the study:

- Total loadings can be used as a measure of environmental impact of toxic chemicals
- Correction for differences in toxicity can be done using an acceptable dose for humans which is based on a risk of 1 in a million for carcinogens, and a no observable effect level for non-carcinogens
- Costs, but not risks should be discounted
- The appropriate social discount rate is 8 per cent, with sensitivity analyses of 6 and 10 per cent

In consultation with OWMC, the study team chose the cases to consider on the basis of data availability and relevance to Ontario. The cases were assumed to provide a reasonable range of unit costs against which the OWMC proposal could be compared.

Status of data

The source documents all recognize uncertainty associated with the data presented. In all cases, the estimates of both quantities and costs are best considered indicative, not definitive. Where assumptions are necessary, ones leading to a lower unit cost are used, or a range is presented.

The decisions in the cases considered were not made on the basis of unit costs to reduce loadings.

Toxicity estimates are drawn from other studies for OWMC, and these may not be the same as those used by decision makers in the cases considered.

Main findings

Costs to reduce loadings in the three cases considered range from 0.60 dollars per tonne of toxic equivalent (\$/t.te) to 200 \$/t.te. Actions with costs near both ends of the range have been adopted.

Costs of a mercury cleanup in the Wabigoon River and Clay Lake were estimated at between 160 and 200 \$/t.te. The Ontario Ministry of the Environment, on the basis of a socio-economic analysis, decided not to proceed with the cleanup.

Conclusions and recommendations

The lead regulations are considered the most relevant for comparison with the OWMC proposal for the following reasons:

- a new technology is required to replace existing practice, and the costs are related to avoidance, rather than cleanup
- exposure resulting from loadings of lead and special waste both are likely to occur in populated areas; both of the cleanup cases occurred in areas which are relatively sparsely populated;
- the decision on the lead regulations was the result of an extensive review process with input from many sectors of society.
- the decision not to proceed with the Wabigoon River remedial program reflected concerns about the effectiveness of the program at reducing impacts, not just concerns about the cost of the program.
- the Kenora PCB spill clean up decision was made relatively quickly under emergency conditions.

The unit costs for reducing lead emissions cannot be considered the upper limit of society's willingness-to-pay; in making the decision, no assessment was made of the cost level at which the proposed regulations would be rejected, and therefore a higher cost may also be acceptable. However, the estimated costs were also considered to be high estimates, and in deciding the costs were acceptable, a lower, unstated level may have been assumed.

1. Introduction

For the purposes of assessing the benefits associated with the operation of the proposed OWMC facility, Environ Corporation has recommended that the change in total loadings to the environment be estimated (Environ, 1987). This approach was recommended because of the difficulties in precisely estimating exposures and specific effects on human health and the environment.

To enable this benefit to be compared against the costs that are associated with the OWMC proposal, the benefit-cost work compares the unit cost of loading reductions (corrected for differences in toxicity) against other unit costs society has indicated that it is willing to endure to avoid environmental loadings. In their report, Environ discusses a number of "benchmarks" against which the OWMC proposal is compared. These benchmarks are based on U.S. examples, which in some cases may reflect different environmental conditions and a different "willingness-to-pay" for preventing environmental loadings.

This paper analyses three case studies applicable to Ontario and Canada:

- mercury cleanup in the Wabigoon/English River system
- cleanup of the Kenora PCB spill
- reduction of lead in gasoline

These three cases were chosen because they are recent, reflect conditions in Ontario (although the reduction of lead in gasoline case is for Canada, the Commission on Lead in the Environment (RSC,185,p45-46) indicated that Ontario had the most to lose and gain from controls on lead), and data are available on both the nature and quantity of materials

involved and the relevant costs. The nature and quantity of materials need to be known in order that corrections can be made for differences in toxicity.

2. Mercury cleanup in the Wabigoon/English River System

2.1. Background

The Wabigoon/English River System is one of the more severely mercury polluted waterways of the world (COSC, 1983). The source of most of the pollution and virtually all of the mercury in the system is a paper mill complex operated in Dryden.

Until 1975, the complex used the chlor-alkali process. Between 1963 and 1970, the plant discharged between 9 and 11 t of mercury into the Wabigoon River. In 1970, the Ontario Water Resources Commission imposed restrictions which lead to a reduction in the discharge of mercury of about 99 per cent. In 1975 the plant was converted to a non-mercury system, and primary and secondary mill waste treatment processes were installed to remove the naturally occurring mercury in the pulp.

Local residents along the system have high blood mercury levels; 98 of the 105 Ontario residents with blood mercury levels in excess of 100 ppb live along the system (MOE, 1986, p28). Concern about residents' health led the federal and provincial governments to investigate various mercury amelioration measures in the Wabigoon/English River System (COSC, 1983, p3).

The short term approach taken was to reduce exposure. Mercury discharged into the river tends to accumulate in fish, and poses risks for fish-eaters, including Native people at two local Indian settlements, and sport fishermen. Commercial fishing has been banned in the area. The Ontario government has recommended not eating the fish and has provided uncontaminated fish to replace local, contaminated supplies. In addition, warnings about eating fish were posted along the system and MOE's annual *Guide to Eating Ontario Sport Fish* advises sport fishermen on "safe" levels of fish consumption (MOE, 1986, p29).

Over the long term, it is desirable to reduce the level of contamination. Two clean-up schemes were considered in detail.

- dredging the Wabigoon River from Dryden to Clay Lake;
- covering Clay Lake bottom sediments with deep or imported material.

Neither scheme alone was considered sufficient.

In January 1986, the Ontario Ministry of the Environment recommended against clean-up operations and identified specific topics on which future research should focus (MOE, 1986). This case thus provides one estimate of an upper bound on what society is willing to pay to reduce environmental loadings.

2.2. Effectiveness of the schemes

Precise measures of the effectiveness of the schemes do not exist. Measuring the effectiveness is complicated by the different toxicities, and relationships between inorganic mercury and the much more toxic methyl mercury. Although the mercury being discharged was inorganic mercury, the primary concern was that this mercury methylates and forms methyl mercury, which is much more toxic. Inorganic mercury has an acceptable daily intake of 0.002 mg/kg/d, whereas methyl mercury's is 5.7×10^{-5} mg/kg/d; methyl mercury is about 35 times more toxic (Environ, 1987).

Given these differences, the MOE studies directed considerable attention at trying to determine the relationship between inorganic and methyl mercury. Unfortunately, the studies were unable to specifically characterize the relationship between inorganic mercury and methyl mercury. However, they were able to show that one existed, and that if no additional mercury (in any form) was added to a lake or river system, a steady-state relationship between methyl mercury in the water and inorganic mercury in the sediments would likely be established within a few days. This point is important for two reasons:

- Clay Lake sediments were not to be removed, only covered - if no sediment/water column mercury relationship existed then the quantity of mercury removed from the system would be nil;
- under non-bioturbid conditions (i.e. little sediment mixing by bottom-dwelling organisms) only the very top layer of sediments, perhaps as shallow as 5 mm, contribute to methyl mercury concentrations in the water column. A deep cover, like the 5 cm proposed, could be assumed to eliminate methyl mercury contribution to the water column.

The clean-up procedure was aimed at reducing methyl mercury concentrations in the long run, however, this was done by removing or covering (so that it is not able to react) inorganic mercury in the river and lake sediments. The reduction in loadings to the environment is thus assumed to be the total quantity of mercury in Wabigoon River and Clay Lake. This quantity is shown in Table 1.

For assessing the effectiveness, estimates have been made assuming that the remedial measures are completely effective (when in fact the source documents expressed considerable concern about the effectiveness), that all the mercury removed is methyl mercury (in reality, not all the mercury is likely to methylate), the mercury removed is disposed of in a secure location that does not load mercury to the environment, and the mercury covered is effectively no longer available. All of these assumptions mean that the assumed quantity estimates are an extremely conservative basis for estimating unit costs of loading reductions (i.e., they overestimate the quantity of reductions and therefore underestimate the cost of reducing loadings).

2.3. Costs of reduction

The costs of reducing the amount of mercury present in Wabigoon River and Clay Lake were estimated by a consultant's study (Acres, 1982). Table 2 presents expected annual cost outlays for dredging the Wabigoon River between Dryden and Clay Lake. The six year program has an estimated total present value cost of between 16 and 19 million dollars (1986Cdn\$)¹. The range reflects different assumptions about contingency factors on the implementation components in years 3 through 6; the low end assumes a contingency factor of 20 per cent, the high end assumes 50 per cent. Although Acres indicates there exists sufficient experience to justify a contingency of 20 per cent, they have recommended using 50 per cent.

Table 3 presents a breakdown of the implementation costs.

In the analysis, the two schemes are assumed to proceed together, and the same equipment is used for both.

¹ These costs are based on an annual discount rate of 8 per cent. Sensitivity of costs to the discount rate is discussed in the appendix.

Table 1:

Estimated quantities of anthropogenic mercury in Wabigoon river and Clay Lake

Watercourse section	Quantity of Mercury by Section (kg)	Cumulative Total from Dryden (kg)	Percentage of Total Mercury Discharged (9080 kg)
Wabigoon River, from Dryden to Wainwright reservoir	1000-3600	1000-3600	11-40
Wabigoon River, Wainwright dam to 30 km downstream of Dryden	1000	2000-4600	22-51
Wabigoon River, 30 km downstream of Dryden to Inlet of Clay Lake	300	2300-4900	25-55
Clay Lake	2000	4300-6900	47-77

Source: Parks et al, 1984.

Notes: Quantities have been rounded to the nearest 100 kg
The cumulative total is the previous cumulative total plus the quantity in the current watercourse section

Table 2:

Expected annual outlays for dredging the Wabigoon River between Dryden and Clay Lake

Year	Items	Contingency of 20%			Contingency of 50%		
		Costs (1981\$)	Costs (1986\$)	Discounted Costs (1986\$)	Costs (1981\$)	Costs (1986\$)	Discounted Costs (1986\$)
1	Field studies	370,000	465,000	465,000	370,000	465,000	465,000
	Administration	<u>12,000</u>	<u>15,000</u>	<u>15,000</u>	<u>12,000</u>	<u>15,000</u>	<u>15,000</u>
	Total for Year	382,000	481,000	481,000	382,000	481,000	481,000
2	Field studies	30,000	38,000	35,000	30,000	38,000	35,000
	Dredging testing	80,000	101,000	93,000	80,000	101,000	93,000
	EA studies	10,000	13,000	12,000	10,000	13,000	12,000
	Administration	<u>36,000</u>	<u>45,000</u>	<u>41,000</u>	<u>36,000</u>	<u>45,000</u>	<u>41,000</u>
	Total for Year	156,000	196,000	180,000	156,000	196,000	180,000
3	Implementation	3,800,000	4,780,000	4,046,000	4,750,000	5,976,000	5,058,000
	Monitoring	100,000	126,000	107,000	100,000	126,000	107,000
	Mapping	37,500	47,000	40,000	37,500	47,000	40,000
	Clay Lake survey	25,000	31,000	26,000	25,000	31,000	26,000
	Administration	<u>60,000</u>	<u>75,000</u>	<u>63,000</u>	<u>60,000</u>	<u>75,000</u>	<u>63,000</u>
	Total for Year	4,022,500	5,060,000	4,283,000	4,972,500	6,255,000	5,294,000
4	Implementation	3,800,000	4,780,000	3,722,000	4,750,000	5,976,000	4,653,000
	Monitoring	100,000	126,000	98,000	100,000	126,000	98,000
	Mapping	37,500	47,000	37,000	37,500	47,000	37,000
	Administration	<u>60,000</u>	<u>75,000</u>	<u>58,000</u>	<u>60,000</u>	<u>75,000</u>	<u>58,000</u>
	Total for Year	3,997,500	5,029,000	3,916,000	4,947,500	6,224,000	4,847,000
5	Implementation	3,800,000	4,780,000	3,424,000	4,750,000	5,976,000	4,281,000
	Monitoring	100,000	126,000	90,000	100,000	126,000	90,000
	Administration	<u>60,000</u>	<u>75,000</u>	<u>54,000</u>	<u>60,000</u>	<u>75,000</u>	<u>54,000</u>
	Total for Year	3,960,000	4,982,000	3,569,000	4,910,000	6,177,000	4,425,000
6	Implementation	3,800,000	4,780,000	3,150,000	4,750,000	5,976,000	3,939,000
	Monitoring	100,000	126,000	83,000	100,000	126,000	83,000
	Administration	<u>60,000</u>	<u>75,000</u>	<u>49,000</u>	<u>60,000</u>	<u>75,000</u>	<u>49,000</u>
	Total for Year	3,960,000	4,982,000	3,284,000	4,910,000	6,177,000	4,071,000
	Grand Total	16,478,000	20,730,000	15,713,000	20,278,000	25,510,000	19,298,000

Source: Acres, 1982 as cited in MOE, 1986:77

Notes: MOE gives inconsistent details and totals; details are assumed correct

1 1981\$ = 1.258 1986\$ (StatsCan, 1986), annual discount rate used is 8%

Table 3:

Details of implementation costs for dredging the Wabigoon River
between Dryden and Clay Lake (millions of dollars)

	Equipment	Labour	Other	1981\$ Total	1986\$ Total
Disposal site development	-	1.6	-	1.6	2.0
Trunk pipeline (12 km)	0.7	-	-	0.7	0.9
Moving pipeline	-	1.1	-	1.1	1.4
Dredging machinery	1	-	-	1	1.3
Dredge connecting pipelines	<u>0.4</u>	<u>-</u>	<u>-</u>	<u>0.4</u>	<u>0.5</u>
Sub-total	2.1	2.7	0	4.8	6.0
Booster stations	0.5	-	-	0.5	0.6
Fuel	-	-	0.8	0.8	1.0
Labour	-	3.6	-	3.6	4.5
Field camp	-	-	0.5	0.5	0.6
Pontoon and work boats	0.5	-	-	0.5	0.6
Log clearing equipment	1	-	-	1	1.3
Engineering and management	<u>-</u>	<u>-</u>	<u>1</u>	<u>1</u>	<u>1.3</u>
Sub-total	2	3.6	2.3	7.9	9.9
Total estimated cost	4.1	6.3	2.3	12.7	16.0
Contingency allowance (50%)				0.0	0.0
GRAND TOTAL				12.7	16.0

Source: Acres, 1972:75 as cited in MOE, 1986:76

Note: Using StatsCan GDP implicit price index: 1 1981\$ = 1.258 1986\$
As per source documents, implementation costs are assumed to
be equally distributed over years 3 through 6, as indicated
in Table 2.

2.4. Implications

The studies indicate that between 4.3 and 6.9 t of mercury could be removed from the Wabigoon River and Clay Lake at a cost between 22 and 27 M\$. MOE recommended that the clean-up not proceed. Although this would appear, *prima facie*, to provide an upper limit on society's willingness to pay to reduce environmental loadings, there are several uncertainties surrounding the reasons for the decision. The decision was not made solely on the basis of a comparison of the costs and the possible loading reductions. There are doubts about the effectiveness of the clean-up which entered the decision (MOE,1986,p38,59). In addition it was recognized that much of the damage has already been done; health care and testing programs would have to continue even if mercury levels in fish were reduced. Further, the number of people at risk appears to be declining (MOE,1986,p43). Consequently, the decision not to proceed reflects more than just the cost being considered too high.

There are a number of differences between this case and a requirement to better manage special waste:

- the effects, though of concern, are relatively localized in a sparsely populated area; waste generation and management tend to occur in conjunction with populations
- in the Wabigoon River, loading (and the associated damage) had already occurred; the objective of better waste management is to avoid loadings, and in many ways this is more comparable to the changes made at the pulp mill to avoid further loadings. These changes were implemented.

3. The Kenora PCB spill

3.1. Background

Three Hydro Quebec transformers were shipped on a flatbed truck through Ontario to Alberta. All of the transformers were thought to be empty, but it was later found that one was not, and a crack in a cooling housing (presumably caused by road vibrations) allowed the liquid to leak out. This liquid was caught in a large metal tray placed beneath the transformer which began to slosh at intersections, corners and during sharp acceleration and deceleration spots between Vermilion Bay and Kenora.

On realizing what had happened, the highway "hot spots" were immediately covered by tar and sand until a repaving effort could be completed. In addition, roadways in Kenora (mostly intersections) were "scrabbled" -- i.e. broken up and removed. A secure building was constructed where the 240 200-L drums (45 gallons) from the scrabbling operation remain waiting for destruction. These drums contain a wide variety of materials, ranging from pavement to rubber gloves. The PCB spilled on the highway is still under the pavement.

3.2. Loading reduction

The exact composition of the spilled material is unknown. The PCB content has been estimated at between 40 and 45 per cent PCBs. Staff in the Thunder Bay regional office of the Ministry of the Environment have estimated the most likely PCB content to be 42 per cent (MOE, 1987). Somewhere between 450 and 600 L were missing for a theoretical maximum of 270 L of pure PCB; the MOE believes the true figure to be about 210 L.

In order to make an estimate of the total loading reduction, a number of assumptions must be made. These include:

- the PCB trapped under the highway is considered immobile, and is *not* a loading to the environment;
- the PCB contained in the drums in storage will be secure there until destruction can occur;
- destruction will be done at high efficiency (e.g. 99.9999% DRE) and therefore loadings to the environment from destruction are relatively insignificant, considering the error associated with the quantities to begin with.

Consequently, the reduction in loadings is assumed to be the total quantity of PCBs spilled: 210 to 270 L. This assumption is conservative for the purposes of this analysis in that it leads to an overestimate of the loading reductions and therefore results in a lower unit cost to reduce the loading.

3.3. Costs of reduction

There is limited information available on the costs of the clean-up. MOE has maintained a file of invoices of costs. The costs for the entire clean-up have been broken down as follows:

\$ 230 000	scrabbling, cost of storage building construction
\$ 480 000	MTC's billings for highway reconstruction
\$ 710 000	Total

These estimates do not include regional staff time. Although no extra staff were hired for the clean-up, some overtime was required. Since the spill, a citizens' advisory committee has been set up. Administrative costs, and staff costs associated with this committee have not been included.

The estimates also do not include laboratory costs, which may be significant.

Also excluded is the cost for continual maintenance of the storage facility until destruction occurs, and the costs of the destruction itself.

On the other hand, there is some non-environmental benefit received in repaving of the 10 km of highway, since future maintenance costs were deferred.

For the purposes of this analysis, it is assumed that the total net cost is \$710 000. This is probably a low estimate of total costs.

3.4. Implications

It is conservatively estimated that between 0.21 and 0.27 t of pure PCBs were removed from the environment at a cost of \$710 000 (1986\$). As discussed, there is uncertainty associated with both quantities and costs. Estimates have tried to overstate quantities and understate costs.

In comparing unit costs of this clean-up to other actions to reduce environmental loadings, it should be recognized that these costs are not necessarily costs at the margin; society might have been willing to pay considerably more to reduce this loading, but it was possible to achieve it at this cost. Also, the Kenora spill clean-up measures were done on an emergency basis, and the area affected was quite localized, relative to the area affected by special waste generation and management.

4. Reduction of lead in gasoline

4.1. Background

Lead is a powerful toxin and the largest single source of lead released to the atmosphere is lead antiknock compounds used in motor gasolines (RSC,1986,p.17). When inhaled, atmospheric lead enters the bloodstream. Although there is no clearly demonstrated harm related to observed blood lead levels in Canada, the Commission on Lead in the Environment has concluded that the effects of low levels of blood lead on the functioning of the haematopoietic system (notably heme synthesis) justify reducing blood lead in the population below 1986 levels. On 3 May 1984, the Leaded Gasoline Regulations of the Clean Air Act were amended to reduce the concentration of lead allowable in gasoline. The regulation phases in controls on the allowable levels of lead. The revised controls are 0.77 g/L for gasoline produced before 1 January 1987, 0.29 for gasoline produced between 1 January 1987 and 31 December 1992. Lead will be "virtually eliminated" from gasoline produced after 31 December 1992; for the purpose of this analysis, "virtually eliminated" is assumed to be 0.026 g/L (RSC,1986,p.89).

4.2. Effectiveness of controls

The amount of lead reduction attributable to the controls on lead content in gasoline are sensitive to assumptions about total gasoline fuel demand. Tables 4 and 5 present Environment Canada and industry (the Petroleum Association for the Conservation of the Canadian Environment) estimates of demand, by fuel type, and consequent projections of atmospheric emissions. The projections incorporate the effects of both lead reductions in leaded fuel, and the requirement that light-duty vehicles be equipped with catalytic converters (and therefore use unleaded gasoline). The new vehicle regulations take effect 1 September 1987, as part of Phase 1 of the two phase program (RSC,1986,p89).

4.3. Costs of controls

The reduction in the use of lead antiknock compounds has a direct impact on the lead industry, a profound impact on the antiknock producers and significant effect on the facilities and blending components used in the petroleum refining industry (RSC,1986,p.104). The Commission on Lead in the Environment estimated the cost effects on the petroleum refining industry and the consumer of leaded gasoline.

PACE presented estimates of the capital and operating costs of the scenarios considered by the Commission for the Commission's assessment. These indicated that the industry would need to undertake capital investments of 500 million dollars to meet the 0.29 g/L requirement, and an additional 300 million dollars to meet the 0.026 g/L requirement (1983\$'s;RSC,1985,p34). PACE estimated the capital charges on these investments using a 14 per cent return on capital, and 7 per cent depreciation.

In addition, refinery operating costs and the need for raw materials will increase, as a result of the requirements. Total additional annual refining costs (in the first year of implementation), including the amortization of capital costs, were estimated at 142 million dollars for phase 1, and an additional 303 million dollars for phase 2 (all in 1983\$). Lacking alternatives, the Commission used these costs, but recognized that they are probably maximum estimates. Using the Statistics Canada Gross Domestic Product implicit price index for Canada to convert to 1986 dollars, and using a discount rate of 8 per cent per year gives a present value cost for the phase down from 0.77 g/L to 0.29 g/L of 1714 million dollars, and an incremental cost to decrease from 0.29 g/L to 0.026 g/L of 552 million dollars². The PACE submission to the Commission assumed that these would be incurred to meet the 0.29 and 0.026 g/L requirements in 1987 and 1990 respectively, it has been assumed that these costs would not be significantly different to meet the 0.026 g/L requirement in 1993.

² Sensitivity of these costs to the assumed discount rate is presented in the appendix.

Table 4:

Environment Canada estimates of effects of regulations on lead emissions

	NEB Fuel Demand (GL/a)	Base Fraction Leaded	Fraction Leaded with P1	Base Lead Emissions (t/a)	Lead Emissions with P1 (t/a)	Lead Emissions with P2 (t/a)	Phase 1 Emissions Reductions (t/a)	Phase 2 Incremental Reduction (t/a)	Total Emissions Reduction (t/a)
1987	36.09 *	0.36	0.36	7473	2814	2814	4658	0	4658
1988	35.68 *	0.35	0.35	7236	2725	2725	4511	0	4511
1989	35.31	0.35	0.32	7048	2486	2486	4561	0	4561
1990	34.94	0.34	0.30	6862	2252	2252	4610	0	4610
1991	34.56	0.33	0.27	6678	2022	2022	4656	0	4656
1992	34.19	0.33	0.24	6497	1796	1796	4701	0	4701
1993	33.82 *	0.32	0.21	6318	1575	141	4743	1434	6177
1994	33.57	0.32	0.19	6270	1403	126	4867	1277	6145
1995	33.31	0.32	0.17	6223	1234	111	4989	1124	6112
1996	33.06	0.32	0.15	6176	1068	96	5108	972	6080
1997	32.80	0.32	0.13	6128	903	81	5225	822	6047
1998	32.55 *	0.32	0.10	6081	742	66	5339	675	6015
1999	32.47	0.32	0.10	6066	739	66	5327	673	6000
2000	32.39	0.32	0.10	6051	737	66	5314	671	5985
2001	32.31	0.32	0.10	6036	735	66	5301	669	5970
2002	32.23	0.32	0.10	6021	733	66	5288	667	5955
2003	32.15 *	0.32	0.10	6006	731	66	5275	665	5940
2004	32.15	0.32	0.10	6006	731	66	5275	665	5940
2005	32.15	0.32	0.10	6006	731	66	5275	665	5940
2006	32.15	0.32	0.10	6006	731	66	5275	665	5940
2007	32.15	0.32	0.10	6006	731	66	5275	665	5940
Total				133194	27619	15308	105575	12311	117886

Notes: Total fuel demand (D) is from RSC,1986:315 for years marked with an asterisk

Total fuel demand for other years is linearly interpolated

Fuel demand is assumed constant after 2003

Fraction of leaded gas (FL) demand is also from RSC,1986:315

Base lead content is 0.77 g/L

Phase 1 lead content is 0.29 g/L

Phase 2 lead content is 0.026 g/L beginning in 1993

Emissions are $D \times FL \times \text{lead content} \times FE$

Fraction emitted (FE) is 0.75 (RSC,1986:83)

Table 5:
Industry (PACE) estimates of effects of regulations on lead emissions

	PACE Fuel Demand (GL/a)	PACE Fraction Leaded	Base Lead Emissions (t/a)	Lead Emissions with P1 (t/a)	Lead Emissions with P2 (t/a)	Phase 1 Emissions Reductions (t/a)	Phase 2 Incremental Reduction (t/a)	Total Emissions Reduction (t/a)
1987	29.60	0.43	7350	2768	2768	4582	0	4582
1988	29.10	0.40	6722	2532	2532	4190	0	4190
1989	28.60	0.37	6111	2302	2302	3810	0	3810
1990	28.60	0.34	5616	2115	2115	3501	0	3501
1991	28.60	0.31	5120	1928	1928	3192	0	3192
1992	28.60	0.27	4459	1680	1680	2780	0	2780
1993	28.60	0.24	3964	1493	134	2471	1359	3830
1994	28.60	0.21	3468	1306	117	2162	1189	3351
1995	28.60	0.18	2973	1120	100	1853	1019	2873
1996	29.10	0.16	2689	1013	91	1676	922	2598
1997	29.60	0.14	2393	901	81	1492	821	2312
1998	30.00	0.13	2252	848	76	1404	772	2176
1999	30.30	0.12	2100	791	71	1309	720	2029
2000	30.50	0.10	1761	663	59	1098	604	1702
2001	30.50	0.10	1761	663	59	1098	604	1702
2002	30.50	0.10	1761	663	59	1098	604	1702
2003	30.50	0.10	1761	663	59	1098	604	1702
2004	30.50	0.10	1761	663	59	1098	604	1702
2005	30.50	0.10	1761	663	59	1098	604	1702
2006	30.50	0.10	1761	663	59	1098	604	1702
2007	30.50	0.10	1761	663	59	1098	604	1702
TOTAL			58741	22123	14113	36618	8010	44628

Notes: Total fuel demand (D) to 2000 is from RSC,1986:317
 Fraction of leaded gas (FL) demand is also from RSC,1986:317
 Fuel demand is assumed constant after 2000
 Base lead content is 0.77 g/L
 Phase 1 lead content is 0.29 g/L
 Phase 2 lead content is 0.026 g/L beginning in 1993
 Emissions are $D \times FL \times \text{lead content} \times FE$
 Fraction emitted (FE) is 0.75 (RSC,1986:83)

Although the refinery costs are considered maximum estimates, there are a number of other costs which are not included in the estimates. One of these is the cost of installing catalytic converters on all new light-duty vehicles beginning with the 1988 model year. Another cost excluded is the cost to the anti-knock and lead industries. With US markets contracting rapidly, both domestic and export sales are collapsing. The closure of the industry represents a 35 million dollar write-off of corporate assets, and a 50 million dollar loss to balance of payments (RSC,1985,p37).

The Commission engaged Data Resources Incorporated (DRI) to estimate the effect of the measures at the pump. DRI estimated these at 0.005 and 0.021 \$/L for the 0.29 and 0.026 g/L requirements respectively. Unfortunately, these estimates are not very useful for estimating the unit costs of loading reductions because of the assumed pricing structure, which would spread the costs of the reduction across all the light oil products of the refinery. However, the Commission used these estimates to assess the acceptability of the costs. It was recognized that the increased costs due to the removal of lead are likely to be masked by other price effects on gasoline, such as changes in taxes, crude oil prices and competitive market forces, all of which cause much larger variations in the price of gasoline than will the removal of lead (RSC,1986,p.109). Nevertheless, these costs must be considered real costs and are indicative of society's willingness to pay to reduce loadings, in this case, of lead. However, the 1993 unit costs of 0.021 \$/L *may* be pushing the upper limit of this willingness, since the Commission speculated that new technologies may be developed which could significantly reduce the 1993 cost.

4.4. Implications

Loading reductions and costs as estimated by Environment Canada and industry (PACE) for the years in which the new regulations are introduced are presented in Tables 6 and 7.

The unit cost of reducing loadings of lead as required by Environment Canada's regulations is between 16 000 and 30 000 \$/t for the first measure and about 45 000 \$/t for the reduction from 0.29 g/L to 0.026 g/L (1986 dollars). The range of unit cost for Phase 1 reflects very different estimates of the effectiveness of controls, as presented by Environment Canada and PACE.

Table 6:

Estimated costs of reducing lead emissions using Environment Canada reduction estimates

	Phase 1				Phase 2			
	Emissions Reductions (t/a)	Capital Cost (1983-M\$)	Operating Cost (1983-M\$)	Total Cost to 1986 (1983-M\$)	Incremental Reduction (t/a)	Capital Cost (1983-M\$)	Operating Cost (1983-M\$)	Discounted Total Cost to 1986 (1986-M\$)
1987	4658	240	92	332	0			
1988	4511		89	89	0			
1989	4561		90	90	0			
1990	4610		91	91	0			
1991	4656		92	92	0			
1992	4701		92	92	0			
1993	4743	260	170	430	1434	300	107	250
1994	4867		170	170	1277		95	54
1995	4989		170	170	1124		84	44
1996	5108		170	170	972		73	35
1997	5225		170	170	822		61	27
1998	5339		170	170	675		50	20
1999	5327		170	170	673		50	19
2000	5314		170	170	671		50	17
2001	5301		170	170	669		50	16
2002	5288		120	120	667		50	14
2003	5275		120	120	665		50	13
2004	5275		120	120	665		50	12
2005	5275		120	120	665		50	11
2006	5275		120	120	665		50	10
2007	5275		120	120	665		50	9
Total	105575	500	2792	3292	12311	300	919	552
Unit cost (\$/t)				1622				44828

Notes: Emission reductions are from Table 4.

Capital costs are from RSC, 1985:34

RSC, 1985 assumed Phase 2 would begin in 1990, not 1993. No effect on costs is assumed

Capital costs are spread over 15 years

Operating costs are annual costs (RSC, 1985:34), less capital charges.

Operating costs are assumed variable where demand is falling, fixed where it is rising

Assumed discount rate is 8%

Costs are converted to 1986\$ using GDP implicit price index

1 1983\$ = 1.10061242 1986\$

Table 6:

Estimated costs of reducing lead emissions using Environment Canada reduction estimates

	Phase 1				Phase 2			
	Emissions Reductions (t/a)	Capital Cost (1983-M\$)	Operating Cost (1983-M\$)	Total Cost to 1986 (1983-M\$)	Incremental Reduction (t/a)	Capital Cost (1983-M\$)	Operating Cost (1983-M\$)	Discounted to 1986 (1986-M\$)
1987	4658	240	92	332	0			
1988	4511		89	89	0			
1989	4561		90	90	0			
1990	4610		91	91	0			
1991	4656		92	92	0			
1992	4701		92	92	0			
1993	4743	260	170	430	1434	300	107	250
1994	4867		170	170	1277		95	54
1995	4989		170	170	1124		84	44
1996	5108		170	170	972		73	35
1997	5225		170	170	822		61	27
1998	5339		170	170	675		50	20
1999	5327		170	170	673		50	19
2000	5314		170	170	671		50	17
2001	5301		170	170	669		50	16
2002	5288		120	120	667		50	14
2003	5275		120	120	665		50	13
2004	5275		120	120	665		50	12
2005	5275		120	120	665		50	11
2006	5275		120	120	665		50	10
2007	5275		120	120	665		50	9
Total	105575	500	2792	3292	12311	300	919	552
Unit cost (\$/t)				1714				44828

Notes: Emission reductions are from Table 4.

Capital costs are from RSC, 1985:34

RSC, 1985 assumed Phase 2 would begin in 1990, not 1993. No effect on costs is assumed

Capital costs are spread over 15 years

Operating costs are annual costs (RSC, 1985:34), less capital charges.

Operating costs are assumed variable where demand is falling, fixed where it is rising

Assumed discount rate is 8%

Costs are converted to 1986\$ using GDP implicit price index

1 1983\$ =

1.10061242 1986\$

Table 7:
Estimated costs of reducing lead emissions using industry (PACE) reduction estimates

Year	Phase 1					Phase 2					
	Emissions Reductions	Capital Cost	Operating Cost	Total Cost	Discounted to 1986	Incremental Reduction	Capital Cost	Operating Cost	Total Cost	Discounted to 1986	
1987	4582	240	92	332	336	0					
1988	4190		84	84	78	0					
1989	3810		76	76	65	0					
1990	3501		70	70	55	0					
1991	3192		64	64	46	0					
1992	2780		56	56	37	0					
1993	2471	260	170	430	264	1359	300	107	407	250	
1994	2162		149	149	84	1189		94	94	53	
1995	1853		128	128	66	1019		80	80	42	
1996	1676		115	115	55	922		73	73	35	
1997	1492		103	103	45	821		65	65	28	
1998	1404		97	97	39	772		61	61	25	
1999	1309		90	90	34	720		57	57	21	
2000	1098		76	76	26	604		48	48	16	
2001	1098		76	76	24	604		48	48	15	
2002	1098		25	25	7	604		48	48	14	
2003	1098		25	25	7	604		48	48	13	
2004	1098		25	25	6	604		48	48	12	
2005	1098		25	25	6	604		48	48	11	
2006	1098		25	25	5	604		48	48	10	
2007	1098		25	25	5	604		48	48	9	
TOTAL	43206	500	1594	2094	1290	11633	300	916	1216	552	
Unit cost (\$/h)					29865						47482

Notes:

- Emission reductions are from Table 5
- Capital costs are from RSC, 1985:34, and are spread over 15 years
- RSC, 1985 assumed Phase 2 would begin in 1990, not 1993. No effect on costs is assumed
- Operating costs are annual costs (RSC, 1985:34), less capital charges.
- Operating costs are assumed variable where demand is falling, fixed where it is rising
- Assumed discount rate is 8%
- Costs are converted to 1986\$ using GDP implicit price index (Statistics Canada, 1986)

This case is quite similar to the situation relating to hazardous waste:

- a new technology is required to replace existing practice, and the costs are related to avoidance, rather than clean-up;
- evidence of adverse health effects is lacking, though there is knowledge of the possible health effects of exposure at high doses to the toxic agents;
- exposure resulting from loadings of lead and special waste both are likely to occur in populated areas; both of the clean-up cases occurred in areas which are relatively sparsely populated.

As in the case of the Kenora spill, it must be recognized that these costs are not necessarily at the margin. Society might have been willing to pay more to achieve the same levels of reduction, but this was not necessary. However, as the Commission makes clear, it received considerable pressure from industry groups arguing that the costs to them were not justified by the likely reductions in effects. Also, the Commission argued that it considered the industry-supplied cost estimates were probably maximum estimates.

The process by which the decision was made to proceed with regulations lends credibility to the use of these numbers as a measure of society's willingness-to-pay. The Commission on Lead in the Environment was established in 1984 to provide independent advice on the present and future risks and areas of concern resulting from the presence of lead in the Canadian environment and to consider and propose corrective measures to reduce the environmental and health risks associated with lead which may be adopted (RSC,1985,p.v). In fulfilling this mandate, the Commission sought opinions from community and public interest groups, governments and industry, held intensive workshops and received numerous written briefs and opinions (RSC,1985,p1).

It should be noted, however, that the Commission did not make its decision on the basis of a present value approach, as presented here, but rather on costs in the first year of implementation. Further, the Commission did not explicitly address discounting of future costs. Using the Commission's approach may make the costs appear as much as five times higher than those presented here.

Because of the similarities of the lead issue to the special waste issue, and the thoroughness of the assessment that lead to the decision to implement regulations to reduce lead in gasoline, the unit costs of reducing lead are the most relevant of the three estimates of society's willingness to pay to reduce loadings to the environment of toxic chemicals.

5. Conclusions

Table 8 summarizes the main findings from the consideration of three cases of proposed or implemented measures to reduce loadings to the environment of toxic chemicals.

The first case considered was a remedial program to reduce the levels of mercury in the Wabigoon River and Clay Lake. Assuming all inorganic mercury eventually becomes the more toxic methyl mercury, the unit cost of reducing the mercury is estimated at between 160 and 210 dollars per tonne (\$/t.te) of toxic equivalents (1986 dollars). The Ministry of the Environment has decided that this program should not proceed. As noted, this reflects several factors:

- uncertainty about the effectiveness of the proposed measures
- low likelihood of significant change in the health effects resulting

The second case considered was a clean-up of a PCB spill at Kenora. The unit cost of the clean-up was estimated at 0.60 to 0.80 \$/t.te. This estimated cost is probably lower than the true cost because of uncertainties in both the reduction in loading, and in the ultimate cost that will be paid.

The third case considered was the program to reduce lead emissions from light-duty vehicles (i.e. automobiles and light trucks). The cost of the more stringent part of the lead phase-down is estimated to have a unit cost of about 190 \$/t.te.

Table 8

Summary of unit costs to reduce environmental loadings

	Quantity (t)	Toxicity (mg/kg/d)	Equiv Quantity (t.te)	Cost (1986-M\$)	Unit Cost (\$/t)	Equiv Unit Cost (\$/t.te)
Inorganic mercury						
low	4.3	5.7E-05	75439	15.71	2796871	159
high	6.9	5.7E-05	121053	19.30	3654126	208
PCBs						
low	0.21	2.3E-07	913043	0.71	2629630	0.60
high	0.27	2.3E-07	1173913	0.71	3380952	0.78
Lead						
phase 1	43206	4.0E-03	10801500	1290	29857	119
phase 2	11633	4.0E-03	2908250	552	47451	190

Notes:

Toxicity data are from Environ, 1987

Equiv. Q corrects for toxicity (see Environ, 1987)

t.te is tonne (toxic equivalent) (Environ, 1987)

The case of lead emissions is considered as the most comparable to loading reductions that might be associated with improvements to special waste management practices because of both the nature of the cases considered, and the process that lead to the decision on lead reductions.

These "benchmarks" can be compared to the costs associated with reducing loadings from special waste management resulting from the operation and use of the proposed OWMC facilities to assess whether or not the OWMC costs to reduce loadings are within the range of other measures society has indicated it is willing to adopt to reduce loadings to the environment of toxic chemicals. However, in making these comparisons, the uncertainty in the estimates of unit costs, as discussed above, must be recognized.

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Appendix A: Sensitivity of analysis to discount rate

Consistent with other analyses being done as part of the benefit-cost program, benchmarks have been evaluated using an annual discount rate of 8 per cent. Tables A-1 and A-2 present the results for discount rates of 6 and 10 percent per year. These tables indicate that the results are not very sensitive to the assumed discount rate.

Table A-1

Sensitivity of unit costs for dredging the Wabigoon River between Dryden and Clay Lake to the discount rate and the contingency factor.

Contingency factor of 20%

Discount Rate	Cost (1986\$)	Low Unit Cost (\$/t)	Low Equivalent Unit Cost (\$/t.t.c)	High Unit Cost (\$/t)	High Equivalent Unit Cost (\$/t.t.c)
6%	\$16,859,264	\$3,920,759	\$223	\$2,443,372	\$139
8%	\$15,712,740	\$3,654,126	\$208	\$2,277,209	\$130
10%	\$14,632,652	\$3,402,942	\$194	\$2,120,674	\$121

Contingency factor of 50%

Discount Rate	Cost (1986\$)	Low Unit Cost (\$/t)	Low Equivalent Unit Cost (\$/t.t.c)	High Unit Cost (\$/t)	High Equivalent Unit Cost (\$/t.t.c)
6%	\$20,717,724	\$4,818,075	\$275	\$3,002,569	\$171
8%	\$19,298,412	\$4,488,003	\$256	\$2,796,871	\$159
10%	\$17,961,432	\$4,177,077	\$238	\$2,603,106	\$148

Notes: Low costs correspond to a clean-up quantity of 4.3 t

High costs correspond to a clean-up quantity of 6.9 t

Calculation method is as used in tables 2, 3 and 8

Table A-2

Sensitivity of unit costs for reducing lead emissions to the discount rate

Using Environment Canada's fuel demand projections

Discount Rate	Phase 1			Phase 2		
	Cost (1986-M\$)	Unit Cost (\$/t)	Equivalent Unit Cost (\$/t.1e)	Cost (1986-M\$)	Unit Cost (\$/t)	Equivalent Unit Cost (\$/t.1e)
6%	\$2,035	\$19,278	\$77	\$686	\$55,692	\$223
8%	\$1,714	\$16,232	\$65	\$552	\$44,828	\$179
10%	\$1,458	\$13,809	\$55	\$445	\$36,175	\$145

Using PACE's fuel demand projections

Discount Rate	Phase 1			Phase 2		
	Cost (1986-M\$)	Unit Cost (\$/t)	Equivalent Unit Cost (\$/t.1e)	Cost (1986-M\$)	Unit Cost (\$/t)	Equivalent Unit Cost (\$/t.1e)
6%	\$1,477	\$34,175	\$137	\$686	\$58,958	\$236
8%	\$1,290	\$29,865	\$119	\$552	\$47,482	\$190
10%	\$1,135	\$26,271	\$105	\$446	\$38,332	\$153

Notes: Calculated as indicated in Tables 6, 7 and 8.